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SOLUBILITY OF LIME, MAGNESIA, AND POTASH IN SUCH MINERALS AS EPIDOTE, CHRYSOLITE, AND MUSCOVITE, ESPECIALLY IN REGARD TO SOIL RELATIONSHIPS

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While experiments relating to the solubility of lime, magnesia, and potash in various silicates have frequently been carried out,[1] especially with those minerals in contact with a saturated solution of carbon dioxid, there seems to have been relatively little work done upon the degree of action of soil extracts upon the lime, magnesia, and potash present in epidote, chrysolite, and muscovite, all of which minerals are commonly found in soils.

A knowledge of the solubility of the lime, magnesia, and potash in epidote, chrysolite, and muscovite would also be a means of roughly estimating their availability, so far as a soil extract is concerned, for the soil solution is acting continuously upon the neighboring minerals.

The individual factors involved in the experimental work were as follows: The production of a very slightly acid soil extract by the addition of 500 cc. of distilled water every 24 hours to an acid soil from Auxvasse, Missouri, and the extracts combined. The combined extracts were then analyzed. The next steps were the grinding of selected samples of epidote, chrysolite, and muscovite to pass a screen of 100 meshes to the inch and the analysis of the finely ground minerals. Then two 25 cc. blank solutions of the soil extracts, together with 24 nursing bottles with 25 cc. of the soil extract in each in contact with from 0.1 to 1.0 gm. of epidote, 0.1 to 1.0 gm. of chrysolite, and from 0.1 to 0.4 gm. of muscovite, were placed in a thermostat and kept at a temperature of 25° C. for a period of two months. At the end of the period the soluble material filtered from the minerals by Pasteur-Chamberland filters was analyzed, and a correction made for the composite blank solutions, for lime, magnesia, and potash with the results given in Table I. Preliminary to the results given in Table I, an analysis was made of the water

[1] Storer says that silicates of alumina, lime, magnesia, and potash are "decomposed and dissolved to a certain extent by carbonic acid-water, and also even by pure water." (STORER, FRANK H. FIRST OUTLINES OF A DICTIONARY OF SOLUBILITIES OF CHEMICAL SUBSTANCES. p. 549. Cambridge, [Mass.], 1864.)

extract of the soil, which showed it to contain 0.001 per cent of lime, (CaO), 0.003 per cent of magnesia (MgO), and 0.001 per cent of potash (K_2O). After two months contact with the glass bottles in the thermostat, an analysis of the solution gave 0.01 per cent of lime, 0.002 per cent of magnesia, and a trace of potash.

TABLE I.—*Solubility of the lime in epidote, the magnesia in chrysolite, and the potash in muscovite, in contact with a slightly acid soil extract*

[Minerals ground to pass a screen of 100 meshes to the inch]

Sample No.	Lime (CaO) extracted from epidote 2 months in thermostat at 25° C.	Magnesia (MgO) extracted from chrysolite 2 months in thermostat. at 25° C.	Potash (K_2O) extracted from muscovite 2 months in thermostat at 25° C.	Proportion of total lime extracted from epidote.	Proportion of total magnesia extracted from chrysolite.	Proportion of total potash extracted from muscovite.	Total lime in epidote.	Total magnesia in chrysolite.	Total potash in muscovite.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	1.40	1.60	1.80	8.78	1.45	21.12	15.84	34.60	8.52
2	1.95	.35	1.75	12.25	.29	20.54			
3	1.90	.40	1.13	11.93	.49	13.26			
4	.25	.21	.95	1.52	.14	11.15			
5	.24	.18		1.45	.29				
6	.22	.18		1.21	.32				
7	.18	.19		1.07	.29				
8	.20	.11		1.20	[a] Trace.				
9	.22	.13		1.33	.09				
10	.56	.16		3.47	.29				

[a] Probably too low.

The results tend to show that, under the conditions of the experiment, more lime and potash was extracted from the silicates epidote and muscovite, ground to pass a sieve of 100 meshes to the inch, by two months' contact with the soil extract kept at 25°C. in a thermostat, than of magnesia from its silicate in the form of chrysolite similarly ground and subjected to the same conditions.

The removal of such proportionally large amounts of lime and potash from silicates by an acid soil extract would seem to indicate that in time a soil's fertility index, with respect to lime and potash, would under proper conditions of acidity be quite appreciably lowered. That the potash results are truly representative is strengthened by the fact that in percolation experiments tried out by the author a short time ago with dilute acid solutions, such as phosphoric acid and sulphuric acid, in every instance considerable amounts of potash were removed from soil silicates, as was the case also when a peaty soil from Maine intermixed with white mica was shaken up with distilled water and allowed to stand for 24 hours before filtering, the filtrate showing potash to be present in a water soluble condition to the extent of 600 p. p. m.

Because of the small amounts of the samples used in Nos. 1 to 4 in relation to the quantity of solution, it would seem to follow as a natural consequence that the results for those samples would be high and should

not be taken as truly representative, the results including those from samples 4 to 10, taken as a whole, are probably more truly representative of the actual solubility conditions.

(1) In contact with an acid soil extract more potash is removed from muscovite than lime from epidote, or magnesia from chryoslite and that on the whole more lime is extracted from epidote than magnesia from chrysolite.

(2) So far as the solubility of the lime in epidote and the magnesia in chrysolite are concerned, the results are quite constant in samples 4 to 10, with the average for these samples of 0.27 per cent of lime from epidote, and 0.17 per cent of magnesia from chrysolite.

A FIELD STUDY OF THE INFLUENCE OF ORGANIC MATTER UPON THE WATER-HOLDING CAPACITY OF A SILT-LOAM SOIL [1]

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INTRODUCTION

It has long been believed that the increased amount of organic matter in the soil resulting from applications of manure causes an important and beneficial increase in the water supply of crop plants, it both enabling the water to be absorbed more readily during heavy rains and increasing the amount held against downward movement, thus retaining a more generous supply within reach of the roots of the crop plants.

Thorne, in a recent paper (*12*),[2] has raised the question whether organic matter

> possesses a value for soil improvement additional to that of the nitrogen and mineral elements that it may contain

and attributes (*p. 27*) the physical improvement of the soil following the use of manure

> not to the carbonaceous matter of the manure, but to the superior growth of plant roots induced by the nitrogen and mineral elements carried by the manure.

His conclusions are based chiefly upon data from experiments at the Ohio Experiment Station covering a period of 24 years, in which the recovery of nitrogen, phosphorus, and potassium has been higher from sodium nitrate, acid phosphate, and potassium chlorid than from farm manure. As the Ohio experiments

> have been conducted on a soil depleted of its organic matter by a long period of tenant husbandry before the test began and the average yields of the untreated land during the period of the test have been only 7.85 bushels per acre of wheat, 14.70 bushels of corn and 21.76 bushels of oats (*12, p. 26*),

the results would suggest that we have been in the habit of overrating the benefit derived from any increased water-holding capacity of the soil caused by the application of manure, or even that the effect of the added organic matter upon this property may in reality be too slight to have any practical importance.

Entirely satisfactory fields for studies designed to determine the effect of differences in the content of organic matter upon the water-holding capacity of soils are scarce; and with most field soils the bringing about of an appreciable increase through applications of manure as light as those

[1] Published, with the approval of the Director, as Paper [illegible] of the Journal Series of the Minnesota Agricultural Experiment Station.

[2] Reference is made by number (italic) to "Literature cited," p. 277-278.

used in farm practice requires a rather long time. This is well illustrated at Rothamsted by the Broadbalk Field, which has been continuously in wheat since 1843. On plot 2b, which receives 14 tons of farm-yard manure every year, the first 9 inches of soil gained only 0.098 per cent of organic carbon in the 12-year period from 1881 to 1893 (*9, p. 127*), and in 1893, after having received such an annual application for 50 years, or 700 tons per acre in all, the 9-inch layer of soil contained only 1.342 per cent more organic matter than the adjacent plot 3, which during the same period had been continuously cropped without any manure or fertilizers. By starting with a virgin prairie soil rich in organic matter and putting it under continuous clean cultivation, an appreciable lowering of the organic matter can be induced much more quickly, but even in this case a long period is necessary (*6, p. 136*).

On many fields the great variation in texture from place to place, especially in the portion of the soil mass below the reach of the plow, renders any comparison of the relative amounts of useful moisture a laborious task, the differences shown in moisture retentiveness being more dependent upon differences in texture than upon any differences in the content of organic matter that may have been induced by dissimilar methods of manuring, cropping, or tillage. Detailed studies of the uniformity in texture of the plots or fields under comparison have usually been omitted, and, hence, it may easily be that many of the data published in support of the common belief are due simply to the coincidence that soils of a finer texture, while they retain more water, also usually have a higher content of organic matter. Under natural grassland conditions the heavier soils are the richer in organic matter and in general it appears that when conditions of surface drainage and climate are similar, the finer the texture of the soil the higher will be the organic-matter content when equilibrium between the processes of decay and those inducing an accumulation of organic matter have once been attained. Under the conditions of ordinary mixed farming, arable soils will approach more nearly to grassland than to forest conditions.

An unusual opportunity for such a study is offered by some plots at this Experiment Station, laid out by Snyder (*11*) some 25 years ago. In the summer of 1915, incidental to a study of the effect of different systems of cropping upon the composition, properties, and productivity of the silt loam soil of these plots, we obtained some data upon the water-holding capacity. It so happened that the season was characterized by weather conditions especially favorable for revealing any differences which might exist in the water-holding capacity of the soils of the various plots.

DESCRIPTION AND HISTORY OF PLOTS

The land, originally covered by a heavy growth of deciduous trees, had been cleared about 1856, and during the following quarter of a century formed part of a typical grain farm of that period, oats or wheat being

grown upon it every year without the use of clover or manure. In 1883 the university acquired the farm for experimental purposes and the next year the field was seeded to clover, from that time on being kept in a good rotation until in 1893 Snyder (*11, p. 2*) laid it out in six plots as a fertility experiment (fig. 1, A). All available records indicate that the land included in the plots had been treated alike during the preceding 36-year period (1856–1892). Plots 2 and 3 were to be kept in 4- and 5-year rotations, including clover and receiving manure, and each of the others to be devoted continuously to the same grain crop and to receive

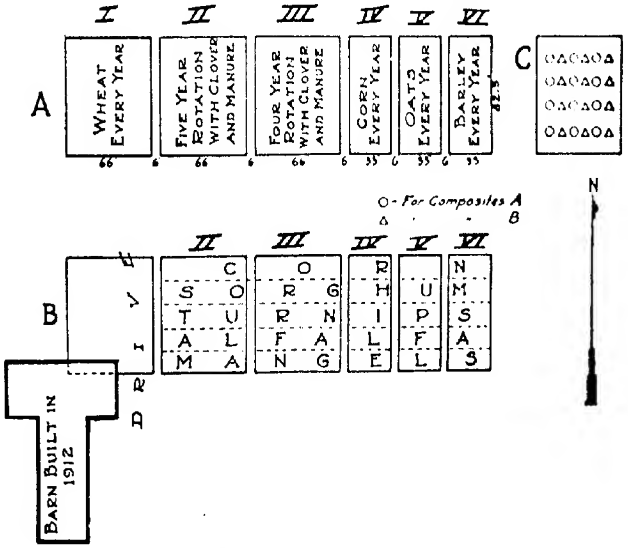

FIG. 1.—Diagram showing arrangement of plots and crops on field J, University Farm, St. Paul, Minn. A is the original plan adhered to from 1893 to 1914, while B shows the cropping plan in 1917. C shows the arrangement of the samples taken for the two composites from a plot.

neither manure nor fertilizer, No. 1, 4, 5, and 6 being planted to wheat, corn, oats, and barley, respectively. The construction of a barn in 1912 upon part of plot 1 has rendered this useless for experimental purposes (Pl. 36).

The present discussion deals chiefly with plots 3 and 4, on the latter of which, beginning with 1893, there had been grown 22 successive crops of corn, without the application of any manure. On the other there had been only 6 crops of corn, but 4 of barley, 7 of oats, and 5 of clover, while 25 tons per acre of manure had been applied, 5 tons with each crop of corn except that of 1897.

Plots 2 and 3 are 5 rods long and 4 rods wide, while the others are of the same length but of only half the width. Each plot is separated from its neighbors by a strip 6 feet wide. The plots have been seeded to the center of this 6-foot strip, the outer edge around each plot being cut away at harvest time.

The soil has been classified by the Bureau of Soils of the United States Department of Agriculture as Hempstead silt loam (*10, p. 26*). The silt loam stratum extends to a depth of from 39 to 50 inches, below which is a thick bed of clean gravel and coarse sand. The surface stratum is very uniform in texture as may be seen from the moisture equivalents reported in Table III.

CULTURAL CONDITIONS

The original plan of the experiment had been carried out until it was interrupted in the spring of 1915, when in order to determine the relative productivity of the different plots we had all five plowed, prepared alike, and planted to the same crops—viz, corn (*Zea mays*), sorghum (*Andropogon sorghum*), turnip (*Brassica rapa*), alfalfa (*Medicago sativa*), and mangels (*Beta vulgaris macrorhiza*)—these being so arranged that each of the five appeared on every plot (fig. 1, B). Weeds were very bad on all the plots except No. 4 but, by frequent use of hoe and horse cultivator, these were kept down in all the crops except the alfalfa. On account of the unusually cool weather, the crops made very slow growth until early in July, and none of the plots at any time appeared to suffer from a lack of moisture.

DISTRIBUTION OF ORGANIC MATTER IN SURFACE FOOT

The ratio of organic carbon to nitrogen in surface soils is so nearly constant that determinations of the latter serve to indicate variations in the content of organic matter. Table I shows the nitrogen content of the successive levels within the first foot of soil on the five plots. The percentages reported in the first part of the table (a) are for composite samples from six borings using a 4-inch plate auger and those in (b) for composites of 24 samples taken by means of a 1.5-inch soil tube of special construction. The latter are really the averages of the data from two sets of samples, A and B, in each of which composites of 12 individual samples were employed, these being distributed as indicated in figure 1, C. The concordance of the data from these two sets, as illustrated by Table II, is such that in the present discussion no purpose would be served by reporting more than their averages. From these data it is evident that any marked differences in nitrogen content, and, hence, in organic matter found between samples from the same level on different plots are to be attributed to differences in crop history and not to the experimental errors of sampling.

Table I.—*Nitrogen and organic matter in successive levels of the surface foot*

(A) NITROGEN IN COMPOSITES FROM 6 BORINGS WITH AUGER

Depth of section	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1 to 3	0.242	0.242	0.176	0.210	0.192
4 to 6	.230	.234	.177	.214	.195
7 to 9	.200	.223	.169	.194	.187
10 to 12	.155	.190	.130	.163	.111
Average	.211	.222	.163	.195	.171

(B) NITROGEN IN COMPOSITES FROM 24 BORINGS WITH TUBE

1 to 6	0.236	0.235	0.180	0.208	0.193
7	.235	.241	.168	.207	.187
8	.212	.232	.163	.203	.170
9	.190	.222	.151	.200	.152
10	.175	.205	.145	.180	.128
11	.160	.192	.126	.158	.116
12	.140	.181	.116	.140	.108
Average	.211	.223	.162	.195	.168

(C) ORGANIC MATTER IN SOME OF ABOVE SAMPLES[a] (= ORGANIC CARBON × 1.724)

1 to 6		5.21	3.97		
7 to 9		5.62	3.79		
10 to 12		4.65	2.41		
Averages		4.76	3.39		

(D) RATIO OF ORGANIC CARBON TO NITROGEN

1 to 6		12.9	12.6		
7 to 9		[illegible]	[illegible]		
10 to 12		12.4	10.8		

[a] The carbon was determined by combustion with copper oxid in a current of oxygen after previous treatment with phosphoric acid.

Plots 3 and 4 show the extremes, the former having the highest and the latter the lowest nitrogen content and at every level plot 3 shows the higher value. The percentages on plot 2 are almost as high as those on 3 while the values for plots 5 and 6 fall between those for 3 and 4. In its low nitrogen content, plot 6 approached 4, the sections below the ninth inch containing even less than the corresponding ones on the latter. The nitrogen content of the first foot on plot 3 was 138 per cent and the organic matter 140 per cent of that on plot 4. These two plots, as they showed the extremes in nitrogen, and, hence, in organic-matter content, while being adjacent, were selected for the more detailed moisture studies.

TABLE II. *Nitrogen content of soil at different levels on plots 2 and 3, illustrating the degree of concordance of the data from duplicate sets of composite samples*

Depth of section	Plot 3.			Plot 4.		
	Set A.	Set B.	Difference.	Set A.	Set B.	Difference.
Inches	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1 to 6	0.229	0.240	0.011	0.182	0.178	0.004
7	.237	.244	.007	.166	.170	.004
8	.230	.233	.003	.167	.158	.009
9	.227	.216	.011	.160	.141	.019
10	.212	.197	.015	.147	.142	.005
11	.199	.184	.015	.124	.127	.003
12	.187	.174	.013	.120	.112	.008
13 to 15	.165	.143	.022	.096	.099	.003
16 to 18	.121	.114	.007	.078	.087	.009

UNIFORMITY IN TEXTURE

The moisture equivalents of the soil from the different levels are reported in Table III. Those for the first 12 inches were determined on composites made by combining equal weights of the duplicate samples reported in Table II, and, hence, they represent composites of 24 individual samples from each plot. The data for the second and third feet are from composites from 6 borings on each plot.

TABLE III. *Moisture equivalents of soil at different levels*

Depth of section	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1 to 6 inches	22.9	24.2	22.8	23.9	24.3
Seventh inch	24.0	24.5	23.7	23.6	24.3
Eighth inch	24.2	25.3	23.2	24.1	24.5
Ninth inch	23.4	24.3	23.3	24.0	24.2
Tenth inch	23.5	24.6	22.7	23.1	24.0
Eleventh inch	23.1	24.1	23.0	23.4	23.2
Twelfth inch	22.1	23.8	22.3	22.6	23.0
Second foot	24.1	23.6	24.0	23.2	24.3
Third foot	23.3	23.2	22.5	23.7	22.9

As was to be expected from the content of organic matter, the lowest values within the surface foot are shown by plot 4 and the highest by plot 3. The differences in the moisture equivalent are very slight compared with those in nitrogen and organic matter; while the nitrogen in the surface foot of plot 3 exceeds that in plot 4 by 38 per cent and the organic matter shows a corresponding difference of 40 per cent, the moisture equivalent is only 7 per cent higher. In the case of the second and third feet, the crop history of the plots appears to have exerted no appreciable influence upon the moisture equivalent, the differences shown in these levels being within the limits of error in sampling.

The uniformity in texture of both the surface soil and subsoil from plot to plot makes the field unusually favorable for such a moisture study. The thickness of the silt loam layer overlying the gravel stratum mentioned above varies from about 30 to 50 inches, in nearly all places it being less than 48 inches, and the variations from place to place on the same plots appear as great as those from one plot to another. While we regularly sampled the fourth-foot section along with the second and third, it showed such an extreme range in texture, owing to the varying proportions of its two component layers, silt loam and gravel, that the data on this level are of no use in the present discussion.

WEATHER CONDITIONS

The weather of the crop season of 1915 was favorable for the maintenance of a very moist soil, being abnormally rainy, cool, and cloudy (Table IV). In each of the first three months, May, June, and July, the precipi-

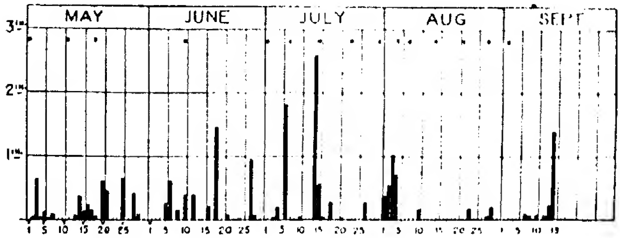

Fig. 2.—Diagram showing the amount and distribution of the rainfall at University Farm, St. Paul, Minn., during part of the season of 1915. The dates of sampling are indicated by asterisks.

tation was somewhat above the normal and in August it was just equal to the normal. For each of the months the mean temperatures varied from 6.1 to 4.2 degrees below normal and the percentage of possible sunshine in the first three months varied from 16 to 26 below normal, while the wind movement was slightly below and the relative humidity slightly above normal.

The precipitation of the autumn of 1914 and the following winter and first two months of spring had been nearly normal, that of April being 2.31 inches. The rainfall of the four months covered by the study came chiefly in the form of slow rains which caused but little run-off; exceptions were provided by two heavy rains, one on July 6 and the other on July 14 (Table V and fig. 2). The dates of sampling happened to be such as to well illustrate the various conditions met with in a wet season. Thus on both July 7 and 15, the samples were taken only a day after a very heavy rain had fallen while on May 18 and August 4 they were taken one day after the last rain in a succession of days with moderate rains.

TABLE IV.—*Weather of the crop seasons of 1915 and 1918 at St. Paul compared with the normal*

PRECIPITATION [a] (INCHES)

Item.	May.	June.	July.	Aug.
Normal	3.34	4.03	3.49	3.36
Departure in 1915	1.01	0.68	2.42	.00
Departure in 1918	.98	−1.18	.41	.20

MEAN TEMPERATURE (° F.)

Item.	May.	June.	July.	Aug.
Normal	58.3	67.8	72.6	69.6
Departure in 1915	−6.1	−5.4	−5.5	−4.2
Departure in 1918	1.6	−1.1	−2.2	.9

SUNSHINE (PER CENT OF POSSIBLE)

Item.	May.	June.	July.	Aug.
Normal	61	66	75	67
Departure in 1915	−26	−16	−20	1
Departure in 1918	− 5	− 5	− 7	−3

WIND VELOCITY (MILES PER HOUR)

Item.	May.	June.	July.	Aug.
Normal	13.0	11.6	9.5	9.5
Departure in 1915	−.9	−1.3	.4	.4
Departure in 1918	−.3	−.2	−.5	.8

RELATIVE HUMIDITY (PER CENT)

Item.	May.	June.	July.	Aug.
Normal	65	69	67	70
Departure in 1915	9	1	5	1
Departure in 1918	1	−3	−5	−2

[a] At University Farm. From September 1, 1914, to April 30, 1915, 11.86 inches, and for the same period in 1917–1918, 6.89 inches.

TABLE V.—*Daily precipitation at University Farm, St. Paul, during the season of 1915*

Day.	May.	June.	July.	Aug.	Sept.	Day.	May.	June.	July.	Aug.
1				0.39		17	0.16			
2	T			.57		18	.07	1.46	0.29	
3	0.65		0.04	1.04		19			T	
4	.04		.19	.74		20	.62		T	
5	.12	0.26				21	.47	.10	.03	
6	.03	62	1.82			22	T	T		
7	.09			T	0.10	23		T		0.18
8	T	.17			.07	24		.03	T	
9						25	.66			
10		.40	.04	.18	.08	26		T		
11	T	T			T	27		.96	.29	
12	T	.40			.07	28	.44	.09		.06
13	.10				.24	29	.10			.20
14	.38		2.60		1.40	30				
15	.15		.57			31			T	
16	.27	.22	.04							
						Total.	4.35	4.71	5.91	3.36

T = Trace.

MOISTURE CONTENT OF THE SOIL

Between May 1 and September 2, plots 3 and 4 were sampled 15 times (Table VI) to a depth of 1 foot, the samples being taken in 3-inch sections from three borings in a north and south line across each plot. In the case of each set one boring was in the corn, another in the sorghum, and the third in the mangels, each being close to a crop row. At the time of the first sampling in each month we sampled the second- and third-foot section also, both on these two plots and on the three others (Table VII).

From Table VI it will be seen that on every occasion the surface foot of plot 3 contained more moisture than that of plot 4, and, except on the very last date, the same holds true for the four 3-inch sections. Throughout the first three months the difference ranged between 3 and 5 per cent, being greatest when the sampling occurred soon after the cessation of a rain. During the last half month, at a time when the crops were drawing most heavily upon the soil moisture and there was but little rain, the differences were much less, falling on the average to less than 1 per cent.

There is no evidence that, in general, more water was retained in the second and third foot on plot 3 than on plot 4 (Table VII), although more was found on May 1, which, however, was not long after the frost had disappeared from the subsoil and there had not been time for the downward percolation of the water from the melting snow and the April rains. With the three other plots, the surface foot was intermediate in moisture between plots 3 and 4, the relative moisture content varying roughly with the nitrogen content (Table VII). Only at the time of the first sampling did they, like plot 3, show a higher moisture content in the second and third foot than plot 4.

The above remarks apply directly to the total water content, which includes both the nonavailable and the available. As the portion of the soil moisture available to plants for growth and for the maintenance of life appears to be approximately that in excess of the hygroscopic coefficient (*1, p. 122; 2*), and as the latter value is a little lower for the surface of plot 4, being only 7.7 compared with 8.1 for plot 3 (Table VIII), we regard the differences in useful water as slightly greater than those in the total water reported in Table VI.

INFLUENCE OF ORGANIC MATTER UPON MOISTURE CONTENT

From the above data it would appear that the greater amount of organic matter in the surface foot of plot 3 is responsible for the considerably higher content of both total and free water shown by it throughout most of the summer of 1915.

Any advantage possessed by one plot over another, due to topography, lies with No. 4. The surface of the field is almost level, but after very heavy rains and at the time of the melting of the snow in the spring the last water to disappear from the field is found upon that plot (Plate 36).

TABLE VI.—*Moisture content of the surface foot of plot 4 and the excess of moisture in that of plot 3*

A.—MOISTURE CONTENT OF SOIL OF PLOT 4

Depth of section.	May 1.	May 11.	May 18.	June 10.	July 1.	July 7.	July 15.	July 23.	July 30.	Aug. 4.	Aug. 7.	Aug. 14.	Aug. 21.	Aug. 28.	Sept. 2.
Inches	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1 to 3	24.2 [a]	21.4	27.5	24.9	22.6	28.7	28.3	22.3	22.2	28.0	25.1	20.8	19.3	17.1	17.6
4 to 6		26.1	27.7	27.5	24.9	29.1	27.9	24.9	24.7	28.8	26.4	23.5	22.2	20.2	18.6
7 to 9	25.5 [a]	25.2	27.7	27.9	25.7	29.1	28.5	25.5	25.2	28.4	26.8	24.3	23.0	21.1	19.7
10 to 12		25.5	26.5	27.2	25.2	28.5	28.0	25.2	23.3	29.2	27.3	24.2	23.5	21.8	20.0
Average 1 to 12	24.9	24.6	27.4	26.9	24.6	28.9	28.2	24.5	23.9	28.6	26.4	23.2	22.0	20.1	19.0

B.—EXCESS OF MOISTURE ON PLOT 3 OVER THAT ON PLOT 4

Depth of section.	May 1.	May 11.	May 18.	June 10.	July 1.	July 7.	July 15.	July 23.	July 30.	Aug. 4.	Aug. 7.	Aug. 14.	Aug. 21.	Aug. 28.	Sept. 2.
1 to 3	5.1 [a]	6.7	4.9	4.3	2.4	4.4	5.2	4.8	4.3	5.0	3.9	2.5	1.3	0.6	1.5
4 to 6		3.6	5.8	4.9	5.0	4.2	5.1	4.8	3.9	4.6	3.8	3.0	1.5	3.0	3.2
7 to 9	4.4 [a]	5.4	5.1	3.1	3.7	3.8	3.1	3.9	2.1	2.5	3.3	2.5	2.1	2.9	.1
10 to 12		4.3	6.7	5.1	3.3	4.3	3.0	2.3	3.2	.7	1.4	2.3	1.0	.9	−.2
Average 1 to 12	4.7	5.0	5.6	4.4	3.6	4.1	4.1	3.9	3.4	3.2	3.1	2.7	1.5	1.9	1.1

TABLE VII.—*Moisture content of soil on plot 4 to a depth of 3 feet, at the first of each month and the excess of moisture at corresponding depths on the other plots, arranged to show any relation of these differences to differences in the nitrogen content of the surface foot*

A.—MOISTURE CONTENT

Date and depth of section.	Plot 4.	Excess on other plots.			
		Plot 1.	Plot 2.	Plot 5.	Plot 6.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
MAY 1.					
1 to 6 inches	24.2	5.1	2.6	3.2	3.3
7 to 12 inches	25.5	4.4	2.8	1.2	.1
Second foot	23.2	3.8	2.2	1.2	2.9
Third foot	20.5	4.9	3.3	2.9	−.7
JULY 1.					
1 to 6 inches	23.7	3.7	4.9	1.7	1.4
7 to 12 inches	25.4	3.5	.6	−.1	.7
Second foot	25.1	1.3	−.4	.5	1.1
Third foot	23.7	.9	.2	.6	1.1
AUGUST 4.					
1 to 6 inches	28.4	4.8	4.0	.8	1.7
7 to 12 inches	28.8	1.6	1.1	−.1	.1
Second foot	28.0	.2	.1	−1.3	.4
Third foot	26.5	−1.3	−1.1	−1.6	−1.3
SEPTEMBER 2.					
1 to 6 inches	18.1	2.3	2.7	1.7	2.3
7 to 12 inches	19.8	.0	−1.0	.8	−.8
Second foot	20.0	1.0	−.7	1.0	1.1
Third foot	21.4	1.0	−2.1	.8	.4

B—NITROGEN CONTENT

1 to 6 inches	0.180	0.055	0.056	0.028	0.013
7 to 9 inches	.161	.071	.051	.042	.009
10 to 12 inches	.129	.064	.032	.033	−.012

[a] A single 6-inch sample used instead of successive 3-inch samples.

It is of interest that the differences in moisture content are as great as would be computed on the assumption that the organic matter of this silt loam has the same water-holding capacity as some of the most absorbent peats, some of these, even when well drained, being able to retain 300 to 400 parts of water to every 100 parts of dry peat. The surface foot of plot 3 carries 1.37 per cent more organic matter than the corresponding level on plot 4 (Table I), from which might be computed a difference of about 5 per cent in water-holding capacity.

TABLE VIII. *Hygroscopic coefficients of successive levels on plots 3 and 4*

Depth of section	Hygroscopic coefficient	
	Plot 3	Plot 4
1 to 3 inches	8.1	7.6
4 to 6 inches	8.1	7.6
7 to 9 inches	8.2	7.8
10 to 12 inches	8.1	7.6
First foot	8.1	7.[illegible]
Second foot	7.9	8.[illegible]
Third foot	7.7	7.[illegible]

INFLUENCE OF ORGANIC MATTER UPON PROPORTION OF USEFUL MOISTURE

The nitrogen content of the surface foot of plot 3 is 138 per cent and the organic matter 140 per cent of that on plot 4, while the hygroscopic coefficient is only 5 per cent the higher on the former. As a consequence the proportionate increase in free water is much greater than that in total moisture content, and that in growth water still greater. Thus, the average moisture content of the surface foot for the nine samplings in May, June, and July was 26 per cent on plot 4 and 30.3 per cent on plot 3, the free water 18.3 and 22.2, and the growth water 13.5 and 17.1, respectively, corresponding to increases of 15, 21, and 27 per cent.

Thus, the difference in organic matter content, owing to differences in the manuring and cropping of the two plots, caused a marked difference in the amounts of useful moisture during the season of 1915 as is well illustrated by a comparison of the ratios of the moisture content to the hygroscopic coefficient (Table IX). The advantages of expressing the moisture condition of soils by such ratios has been discussed in several recent papers (*3, p. 55; 4, p. 453; 5, p. 266*). The expression "hygroscopic coefficient = 10.0; ratio = 1.7" indicates a moisture content of 17.0 per cent, a wilting coefficient of 15.0[1] (*8, p. 65*), 7 per cent of free water, and 2 per cent of growth water. The ratios 1.0, 1.5, and 2.0 – 2.5 appear to indicate, respectively, the minimum to which crop

[1] The exact figure is 14.7.

plants can reduce the soil moisture (*l*), the point at which root penetration practically ceases (*7, p. 279*), and the water-retaining capacity of well-drained arable mineral soils (*3, p. 69*), and such an expression as the above makes all these relations apparent at a glance. The ratio may be used alone to indicate the *relative moistness*, while its combination with the hygroscopic coefficient expresses the *moisture condition*.

TABLE IX.—*Ratio of moisture content to hygroscopic coefficient at different levels on plots 3 and 4, in 1915*

Date.	Ratio on plot 4.			Excess of ratio on plot 3.		
	First foot.	Second foot.	Third foot.	First foot.	Second foot.	Third foot.
May 1	3.2	2.6	2.7	0.4	0.8	0.6
11	3.2			.4		
18	3.6			.5		
June 10	3.5			.4		
July 1	3.2	3.1	3.2	.3	.2	.0
7	3.8			.3		
15	3.7			.3		
23	3.2			.3		
30	3.1			.3		
Aug. 4	3.8	3.5	3.5	.1	.1	—.2
7	3.4			.2		
14	3.0			.2		
21	2.9			.0		
28	2.6			.1		
Sept. 2	2.5	2.5	2.9	.0	.1	.0

The high ratios observed in the subsoil of these plots is probably due to the retarding influence which the substratum of gravel and coarse sand exerts upon the downward movement of water (*3, p. 34–41*).

In a study somewhat similar to the one here reported, but made in eastern Nebraska in 1912, one of us (Alway) found a similar influence of the organic matter upon the amount of useful moisture retained (*4, p. 474*), but there the conditions were not so satisfactorily comparable, an exposed subsoil poor in organic matter being compared with an adjacent surface soil.

MOISTURE RELATIONSHIPS AND PRODUCTIVITY IN LATER SEASONS

Plot 3 showed itself far the more productive of the two plots in 1915, as had been the case also in such of the preceding 22 years of the experiment, as the coincidence of the corn crop on plot 3 permitted a direct comparison of yields (Table X). In 1916 spring wheat was sown upon all five plots and the yields were relatively unchanged. However, red clover (*Trifolium pratense*) was seeded with the wheat and while the stand of clover plants was even and moderately thick on all the plots, it was especially fine on No. 4, and in the following year the yield of hay was considerably the greater on this plot and the aftermath also was

heavier than on No. 3. The second growth, being too light to make a fair cutting of hay, was plowed under and the field seeded to winter rye (*Secale cereale*), which gave a good yield in 1918, it being almost as heavy on plot 4 as on plot 3. The yield of hay, straw, and grain combined, for 1917 and 1918, amounted to 9,738 pounds per acre on plot 4, compared with 9,088 pounds on plot 3. Evidently the lessened water-holding capacity on the former had no serious effect upon the crop yields.

TABLE X.—*Relative productivity of plots 3 and 4*

Season.	Crop.	Yield per acre. Plot 3.	Yield per acre. Plot 4.	Productivity of plot 4.[a]
1896	Corn:			
	Grain, bush	61.7	44.0	71
	Stover, cwt	44.8		
1897	Grain, bush	33.3	10.0	33
	Stover, cwt	18.8	6.2	33
1901	Grain, bush	40.6	37.8	93
	Stover, cwt	20.4	26.4	129
1905	Grain, bush	71.1	26.6	37
	Stover, cwt	20.8	12.8	62
1909	Grain, bush	96.6	48.9	51
	Stover, cwt	25.6	31.4	123
1915	Grain, bush	79.7	55.0	69
	Stover, cwt	56.0	44.0	78
	Sorghum, as cut green, cwt	16.4	12.6	77
	Turnips:			
	Roots, tons	12.9	7.4	58
	Tops, tons	3.4	1.5	44
	Mangels:			
	Roots, tons	20.7	11.4	55
	Tops, tons	2.9	1.8	62
1916	Wheat:			
	Grain, bush	29.6	20.5	69
	Straw, cwt	35.2	24.5	70
1917	Clover hay, tons	2.0	2.44	122
1918	Winter rye:			
	Grain, bush	40.3	38.3	95
	Straw, cwt	26.7	25.6	96

[a] Yield on plot 3=100.

The moisture content of the soil on the two plots was determined on four occasions during the past season, and, in general, plot 3 was found the more moist in the surface 6 inches (Table XI). When, as in Table XII, we compare the ratios of moisture content to hygroscopic coefficient with those for 1915 (Table IX) it is evident that there was little difference between the two plots in the moisture content of the whole three-foot section in 1918; the subsoil on both plots was much drier than in the earlier year, so dry in fact that until the rains of November fell (Table XIII), there was no opportunity for loss of water by percolation from this section. The dryness of the third foot indicates that it had been fully occupied by the rye roots and hence that all the water

that entered the surface had been retained within reach of the roots. With forage crops like clover, where a still larger amount of moisture is required for maximum yields, the same would hold true.

TABLE XI.—*Differences in moisture content of soil of plots 3 and 4 in season of 1918*

Date and depth of section.	Plot 4.	Plot 3.	Excess on plot 3.
June 11 (1.82 inches of rain on June 8 to 10):	*Per cent.*	*Per cent.*	*Per cent.*
1 to 6 inches	24.8	27.8	3.0
7 to 12 inches	25.1	26.4	1.3
Second foot	19.9	17.7	−2.2
Third foot	13.0	12.4	−0.6
June 26 (Only 0.15 inch of rain since June 10):			
1 to 6 inches	10.8	11.4	0.6
7 to 12 inches	14.5	13.4	−1.1
July 18 (1.89 inches of rain on July 14-16, 2.78 inches since June 26):			
1 to 6 inches	21.6	23.3	1.7
7 to 12 inches	19.6	19.1	−0.5
Second foot	12.0	10.7	−1.3
Third foot	11.5	12.0	0.5
Nov. 12 (2.32 inches of rain Nov. 1 to 8; 8.63 inches since July 18):			
1 to 6 inches	25.2	27.1	1.9
7 to 12 inches	25.1	27.6	2.5
Second foot	24.4	25.1	1.7
Third foot	16.0	16.5	0.5

TABLE XII.—*Moistness of soil on plots in 1918 compared with that in 1915, showing the much drier condition of the subsoil in the former year*

Plot No. and depth of section.	Ratios in 1918.			Ratios in 1915.		
	June 11.	July 18.	Nov 12.	July 7.	Aug. 4.	Sept. 2.
Plot 3:						
First foot	3.3	2.6	3.4	3.5	3.9	2.5
Second foot	2.2	1.4	3.2	3.3	3.6	2.6
Third foot	1.6	1.5	2.1	3.2	3.3	2.9
Plot 4:						
First foot	3.2	2.7	3.3	3.2	3.8	2.5
Second foot	2.5	1.5	3.0	3.1	3.5	2.5
Third foot	1.7	1.5	2.1	3.2	3.5	2.9

In general, it appears that percolation causes but little loss of the summer rainfall in the case of soils as fine in texture as the silt loams when these are in grasses or small grains, the portion of the subsoil occupied by the roots intercepting and giving up to the crop any of the moisture that penetrates through the surface foot. On fields with a sharply rolling surface a lowered water capacity, due to loss of organic matter, might be accompanied also by greater difficulty of penetration, and hence by a sufficiently greater loss by run-off to cause a markedly lower crop yield.

The comparatively slight influence that the water-holding capacity of the surface soil alone exerts upon the productivity finds an illustration in the common observation that sandy loams provided with fine-textured subsoils, when properly farmed, produce as heavy yields as clay loams.

The moisture available to a crop, in so far as the character of the soil determines the amount, depends upon the water-retaining capacity of the whole soil section penetrated by the roots of the crop, and not chiefly upon that of the surface stratum, and while cultural methods which lessen the organic-matter content of this stratum lower its water-retaining capacity, it forms such a small part of the whole moisture-retaining section that any change in the moisture supply thus induced may be too slight to have any distinct influence upon the productivity.

SUMMARY

The paper reports a detailed study of the moisture conditions found on two adjacent Minnesota plots, both of which had a silt loam soil, very uniform in texture, but differing widely in content of organic matter as the result of great differences in cultural treatment.

During the cool, wet summer of 1915, when cultivated crops were grown, the surface foot, and this alone, showed a very marked difference in the moisture content, especially in the available portion, the soil the richer in organic matter retaining the more water; but in the warmer and somewhat drier summer of 1918, when winter rye was used, much smaller differences were found.

It is concluded that in the case of a finer-textured soil, with a fine-textured subsoil and a comparatively level surface, the differences in the watery capacity that may be caused by differences in manuring or in cultural operations exert but little influence upon the productivity.

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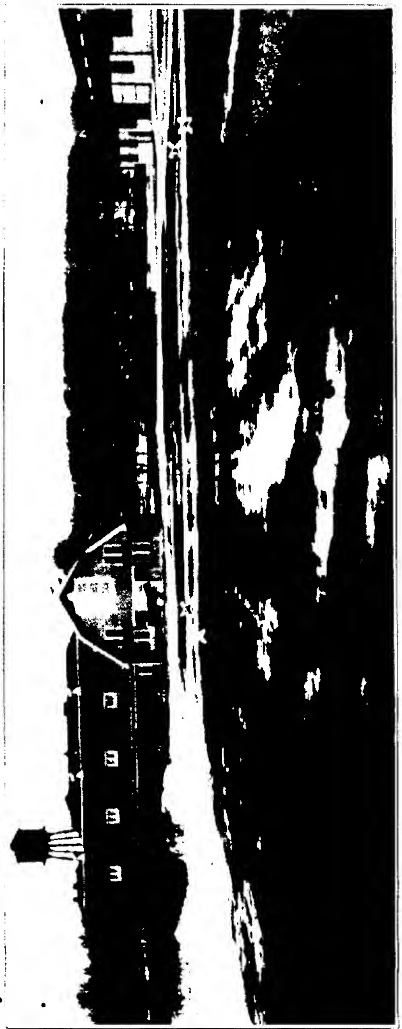

PLATE 36

View of Field J., Minn. Agr. Experiment Station Farm, showing topography and surroundings, looking from plot 6 to the barn which occupies part of plot 1. The photograph, taken on the morning of February 27, 1918, as the snow was disappearing, shows plot 4 to be slightly the lowest, the two streaks of ice from north to south, marked by crosses, both being on the plot. The water, held back by the snow bank at the left, had frozen during the night.

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